

Laser Microfabrication of Neural Electrode Arrays: Comparison of Nanosecond and Picosecond Laser Technology

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Abstract

Microfabrication of neural electrodes using a Nd:YAG laser for cutting platinum foil and medical grade silicone rubber is an established process since many years. However, limitations of this technology are well known and are related to the laser wavelength (533 nm or 1064 nm) but more dominantly to the pulse width (some nanoseconds). New lasers that emit pulses in the lower picosecond range at 355 nm provide much more precise ablation and overcome a major drawback of nanosecond technology: Picosecond lasers allow selective ablation of optically transparent materials such as silicone rubber and Parylene C with very smooth cut edges and dramatically improved definition.

Keywords: neural electrode, laser, fabrication, picosecond, nanosecond, silicone, metal, parylene

Introduction

In 2004 a technology for laser-based microfabrication of neural electrode arrays was developed that exclusively uses traditional implant materials such as medical grade silicone rubber and high purity platinum foil [1]. In the following years, this technology was improved by switching to fast and very cost effective marking lasers [2], by introduction of other metals such as medical grade stainless steel and platinum iridium [3], multiple metal layers were introduced [4], microfluidic channels were integrated into the rubber [5], metal tracks became stretchable [6], electrode arrays were shaped three-dimensionally [7], additional layers of Parylene C for mechanical robustness [8] and improved dielectric strength [9] were incorporated and electrical interconnection technology was established [10]. Biocompatibility of this technology was demonstrated in cytotoxicity tests [11] and long-term animal studies [12].

Materials and Methods

Basic Fabrication Process

The fabrication process starts with spin coating of a layer of n-heptane diluted silicone rubber adhesive (MED 1000, Nusil, Carpinteria, USA) on a mechanical carrier to a layer thickness of some 10 µm. Before complete curing, metal foil (e.g. 12.5 µm platinum, 99.95%) is laminated to the rubber. The metal is patterned with a laser in a way that a fine trench is cut describing the contour of

the of electrode sides, contact pads and tracks. All excess metal is removed manually with tweezers, leaving tracks, pads and electrode sites sitting on the rubber. A covering layer of some 10 µm of silicone rubber is deposited. In a second laser process, the rubber is removed from the electrode sites and contact pads and the perimeter of the electrode array is cut. Finally, the electrode array is lifted from the carrier. A typical example of a laser-fabricated electrode array is shown in Fig. 1.

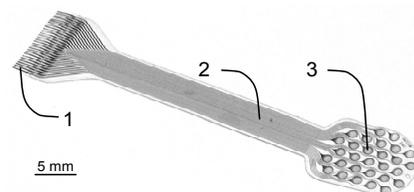


Fig. 1: Laser-fabricated cortical electrode array. 1: contact pads, 2: integrated tracks, 3: electrode sites

Nd:YAG Laser Processing

We used a Q-switched Nd:YAG laser for cutting metal foil and patterning the silicone rubber. However, lasers of this technology usually generate pulses that have a width of 30 to 90 ns and the native wave length is 1064 nm (infrared) which interaction with matter is predominantly of thermal nature. The impact of such a light pulse on metal causes instant melting, splashing, and solidifying of splashed metal. Polymers, such as silicone rubber and Parylene C are transparent for infrared light. Interaction with the laser beam is

based on thermal processes ignited on the surface underneath the polymer, blasting off the transparent top layer, resulting in very rough cut edges and rather wide cut trenches, limiting the minimal achievable feature size.

Picosecond Laser Processing

In our pilot investigations a passively mode-locked Nd:Vanadate laser was used to obtain short picosecond pulses. If the width of a laser pulse is in the range of 10 ps and below, thermal effects are negligible. The underlying light-matter interaction is still controversial to some degree. One explanation is that ablation of material is based on stripping electrons from the atom shell, causing the remaining nuclei to undergo a Coulomb explosion. No melting of material with accompanied burning, stress crack, extended melting zones, etc. is involved. Although, the short laser pulse interacts with the first material in its way, almost independent from its optical properties.

Comparing Both Laser Technologies

Using a nanosecond as well as a picosecond laser (see Tab. 1), trenches were cut through silicone rubber (100 μm thickness), platinum foil (12.5 μm), and Parylene C (10 μm). The laser parameters were varied to achieve the highest definition and smoothest cut edge.

Tab. 1: Features of the two lasers used

	Nanosecond Laser	Picosecond Laser
model	DPL Genesis Marker	Super Rapid
medium	Nd:YAG	Nd:YVO ₄
supplier	cab GmbH, Karlsruhe, Germany	Lumera Laser, Kaiserlautern, Germany
pulse duration	30 ns - 60 ns	< 15 ps
pulse freq.	1 Hz - 40 kHz	80 kHz - 1 MHz
wavelength	1064 nm	355 nm
optics	210 mm focal length 120-120 mm ² work field	103 mm focal length 45-45 mm ² work field
beam focus	35 μm	18 μm

Results

The nanosecond pulse regime allows fabricating microelectrode tracks of 25 μm width. Because patterning is based on melting, processed metal splashes in the trench cut between two adjacent tracks, establishing an undesired electrical contact. Hence, for obtaining two parallel tracks, three tracks are patterned and the central track functioning as a shadow mask for the silicone substrate underneath is removed manually in order to exclude the possibility of shortened tracks. This concept is well established and results in a parallel

track pitch of 85 μm and 60 μm track separation, using an effective cutting velocity of $v = 0.5$ mm/s.

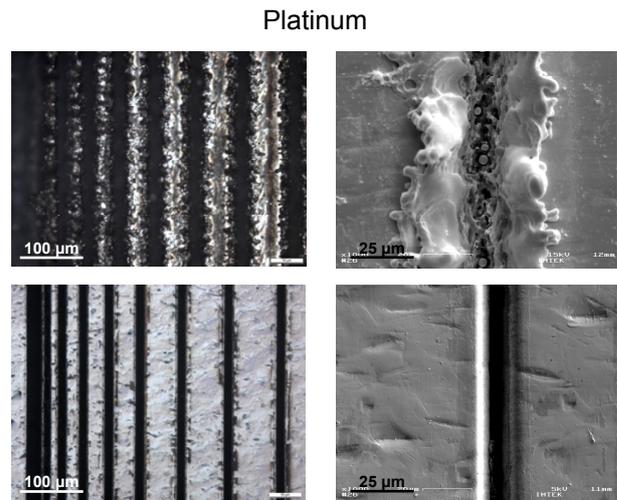


Fig. 2: Laser cuts through 12.5 μm platinum foil. The dark areas represent ablated platinum. Top: nanosecond pulse regime. Bottom: picosecond pulse regime. Left: optical images; right: scanning electron micrographs

Picosecond laser technology allows the fabrication of smaller feature sizes in platinum foil with track widths down to 12 μm and a track separation of 13 μm resulting in a pitch of 25 μm ($v = 200$ mm/s). The absence of metal splashing into the cutting trench due to the lack of thermal heating ensures an electrical insulation of adjacent tracks. No shadow masking and manual removal of metal is required. Fig. 2 shows pictures taken with an optical and a scanning electron microscope, illustrating the difference between the trenches cut.

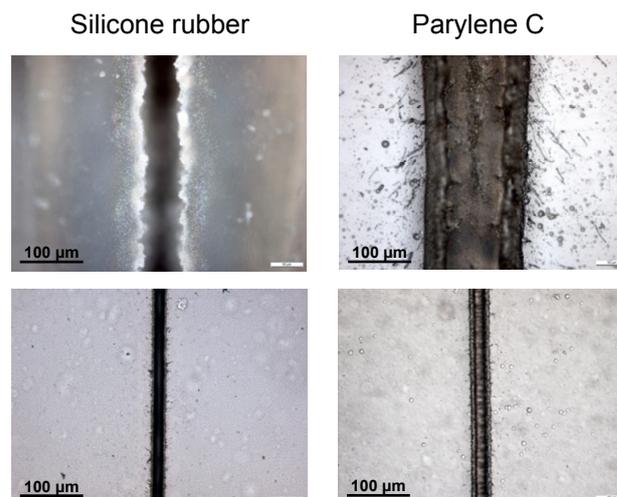


Fig. 3: Laser cuts through silicone and parylene C. Dark areas indicate ablated material Top: nanosecond pulse regime. Bottom: picosecond pulse regime

Profile depths p of the cut edges were obtained by optical microscopy providing a measure of rough-

ness related to the measuring length of 0.5 mm. We found $p = 7.8 \mu\text{m}$ for nanosecond pulses and $p = 0.6 \mu\text{m}$ for picosecond pulses.

Laser ablation of polymers is by far more difficult when thermal effects are present because the beam is burning the material rather than cutting it. In silicone rubber, no cuts narrower than $60 \mu\text{m}$ were achieved using nanosecond technology ($v = 1 \text{ mm/s}$, $p = 22.1 \mu\text{m}$). In Parylene C, a minimal trench width of $100 \mu\text{m}$ ($v = 10 \text{ mm/s}$, $p = 9.4 \mu\text{m}$) emphasises this phenomenon even stronger. On the other hand, using picosecond pulses, trenches of $15 \mu\text{m}$ width were cut into silicone rubber ($p = 5.8 \mu\text{m}$) and Parylene C ($p = 1.6 \mu\text{m}$), respectively, both at $v = 200 \text{ mm/s}$ effective cutting velocity. Fig. 3 shows optical images of both materials, laser processed with different pulse durations.

Discussion

We observed that the two laser interact very differently with the materials. While nanosecond pulse processing strongly depends on optical absorption and thermal alteration of the material, picosecond pulses neatly ablate layer by layer of the material the beam hits, regardless of optical transparency.

Conclusions

The use of picosecond lasers permits micro-fabrication of neural electrode arrays in much higher definition, permitting at least three times smaller feature sizes and higher integration densities of electrode contacts and conductor tracks. Cut edges of silicone rubber substrates are three to four times smoother and are therefore believed to be easier for the immune system to cope with. Compared to our traditional laser set up including a nanosecond marking laser, the picosecond laser allows at least 100 times faster material processing. Therefore we believe that this technology is suitable for economical micro-fabrication of robust neural electrode arrays made from silicone rubber, platinum foil and Parylene C.

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